

Applied Geophysics

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1. APPLIED GEOPHYSICS: ASSISTANCE IN THE INVESTIGATION OF RAW MATERIALS

When investigating raw materials, the geologist is often confronted with many problems such as: thickness of overburden, localisation of lithological contacts or geometry of the deposit in complex geological situations. A geophysical reconnaissance can assist the geologist: to accurately define the geometry of the deposit between the drilling locations, to determine the waste/ore ratio, as well as the accurate reserves of raw materials. Due to high costs, the number of drill holes which can be done is limited. Accurate correlation between them is not always assured and potential nasty surprises can arise during the quarrying.

Applied geophysics may also be helpful for the determination of the physical characteristics of the rocks, i.e. rippability. In the quarry, detailed geophysics can determine cavities. In a karstified deposit, this geophysical reconnaissance can overcome quality fluctuations caused by the cavity materials. A constant quality can be maintained.

2. APPLIED GEOPHYSICS: MANY ADVANTAGES AT LOW COST

The main advantages of geophysics are as follows:

- ◆ Investigation over a greater surface
- ◆ expedient execution
- ◆ results in form of maps and profiles
- ◆ accurate calculation of reserves
- ◆ planning of the drilling campaign
 - optimisation of the drilling location
 - reduction of the quantity of drilling
- ◆ Lower costs

Table 1 compares the cost of a geophysical investigation with that of a theoretical drilling campaign in a gravel deposit.

Table 1

		Geophysics	Drilling
Logistic	portable	heavy drilling machine	
Data	Information	17 vertical electrical soundings	17 drill holes (850 m)
	Additional exploration	3 drill holes (150 m)	none
Duration	Field acquisition	4 days	85 days
	Interpretation	2 days	3 days
	Additional drilling	15 days	-
	Total	21 days	88 days
Cost		geophysics: 10'400 US\$	88'000 US\$
		add. Drillings: 16'000 US\$	
	Total	26'4000 US\$	88'000 US\$

drilling advance: 10 m/day drilling cost: 100 US\$/m specialist: 1000 US\$/day
 2 labourers: 300 US/day each geophysical tools: 2000 US\$

The cost of the application of refraction seismics will be within the same range. On the other hand, the cost of the application of reflection seismics would be around 30% more expensive.

Nevertheless, the geophysical methods are indirect methods of reconnaissance. The results are physical values which have to be interpreted in terms of rocks and/or sediments. The experience of the geologist / geophysicist and a good knowledge of the local geology are indispensable prerequisites for obtaining very accurate results. The main disadvantages are as follows:

- ◆ no samples
- ◆ drill hole of calibration

Calibration of the geophysical values within a few drill holes considerably improves the accuracy of the results. It is also advisable to sink two to three drill holes after a geophysical campaign.

3. GEOPHYSICAL METHODS AVAILABLE AND THE CRITERIA OF CHOICE

To solve the above problem, which often appears during the investigation, the geologist has the following methods at his disposal.

3.1 Geoelectrics

An electricity field is emitted by one or two electrodes, and the difference of potential created by this field is measured by two other electrodes. Different types of array are available to the specialist. The most frequently applied arrays for prospecting are as follows:

- ◆ Vertical electrical sounding (VES) Schlumberger type
- ◆ Four pole profiling (4P-PRFL)

The goal of the geoelectrical methods is as follows:

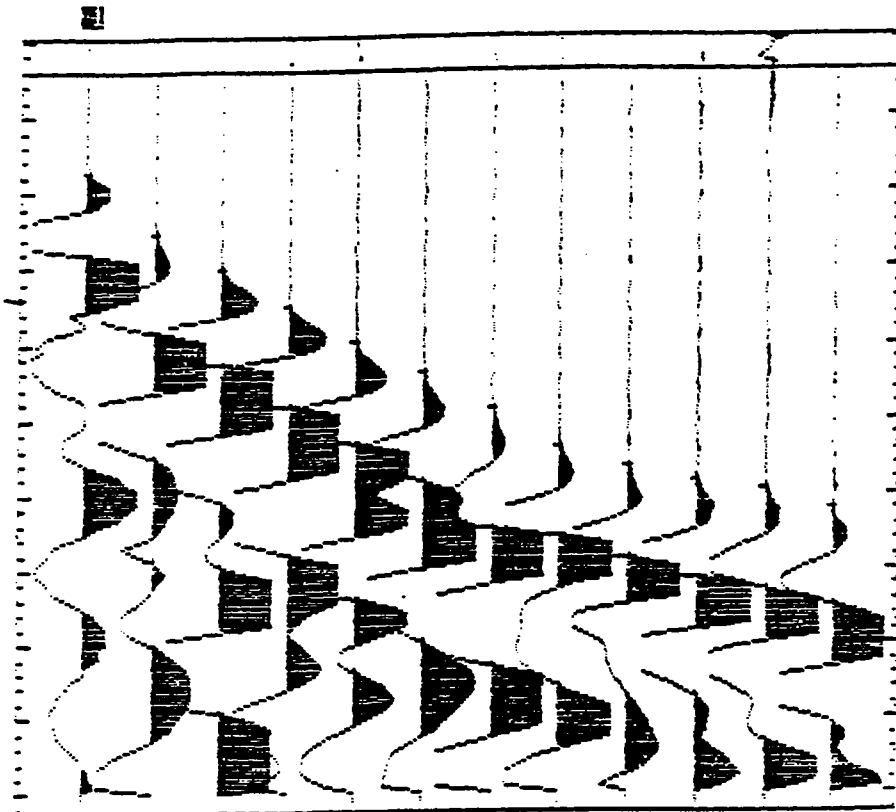
- ◆ With VES, to define the true resistivity . This allows to determine the kind of rocks and the thickness of the formation
- ◆ With 4P-PRFL, to map the distribution of the apparent resistivity. This reveals the structure of the subsurface for a given depth of investigation depending of the array configuration

3.2 Seismics

Waves are artificially generated by means of explosions or hammer within the earth crust. The waves are reflected and refracted on the in homogeneous plans (fault) or on stratification. The wave characteristics and the time during which the seismics waves pass from the emission centre to the geophones are recorded.

In refraction seismics, only the first arrival waves are considered. The Fig. 1 shows a record of refraction seismics. This method is suitable for determination of rock quality (i.e. rippability).

Fig. 1: Traces display



Listing of first breaks of profile

Area : BCPWA Profile : 15 Record : 874
 Shot pos : 3.0 Lay start : 4.0 Lay end : 15.0
 Sampling : 100 Delay : 0.00

Trace	Position	First break	Trace	Position	First break
1	4.00	17.30	2	4.50	
3	5.00	25.40	4	5.50	
5	6.00	30.20	6	6.50	
7	7.00	34.90	8	7.50	
9	8.00	39.70	10	8.50	
11	9.00	43.90	12	9.50	
13	10.00	48.50	14	10.50	
15	11.00	53.70	16	11.50	
17	12.00	56.30	18	12.50	
19	13.00	58.10	20	13.50	
21	14.00	59.30	22	14.50	
23	15.00	61.80	24	15.50	

In **reflection seismics**, all reflected waves are considered. A shallow reflection seismics allows the interpretation of complex geological situation on the subsurface for a few years.

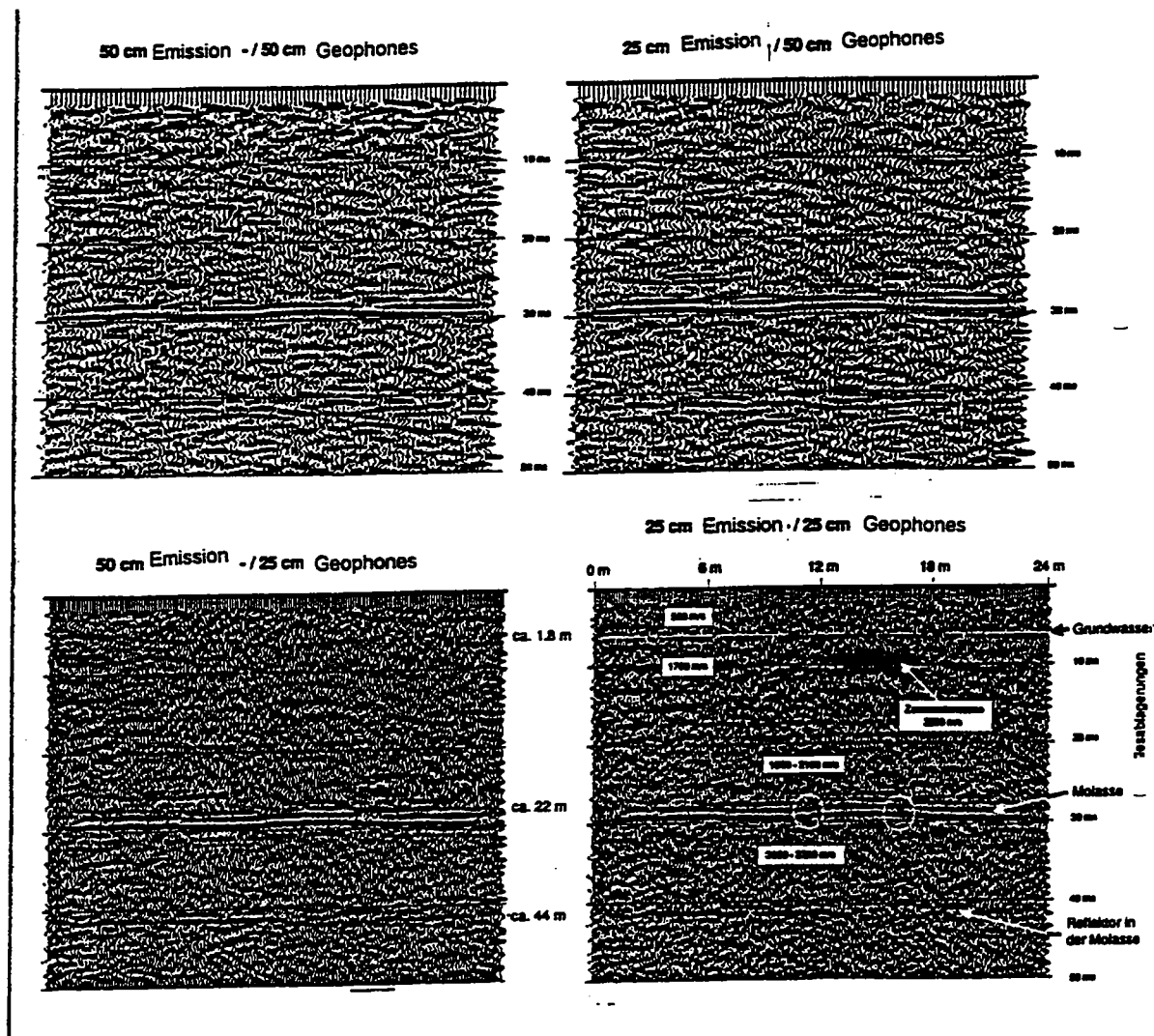
In shallow reflection seismic, acquisition of raw data and its processing must be treated with great care.

In the acquisition of raw data, the distance between the points of emission and the distance between the geophones are very important. These distances influence the data density which can be defined by the two following parameters:

- ◆ Coverage: how often a point on a reflector is reached by a roll along acquisition
- ◆ Common depth point (CDP) corresponds to half the distance between the geophone

An example of the importance of the raw data acquisition is given in Fig 2. The effect of the variation of the data density can be clearly seen.

Fig 2: Results of a shallow reflection seismic for different distance of emission and geophones array.



For shallow seismic surveys, the consistent use of both reflection and refraction profiling is recommended. Although the reflection method is unrivaled for imaging the more complex geological structures, usually better velocities of the subsurface layers are obtained by refraction analysis.

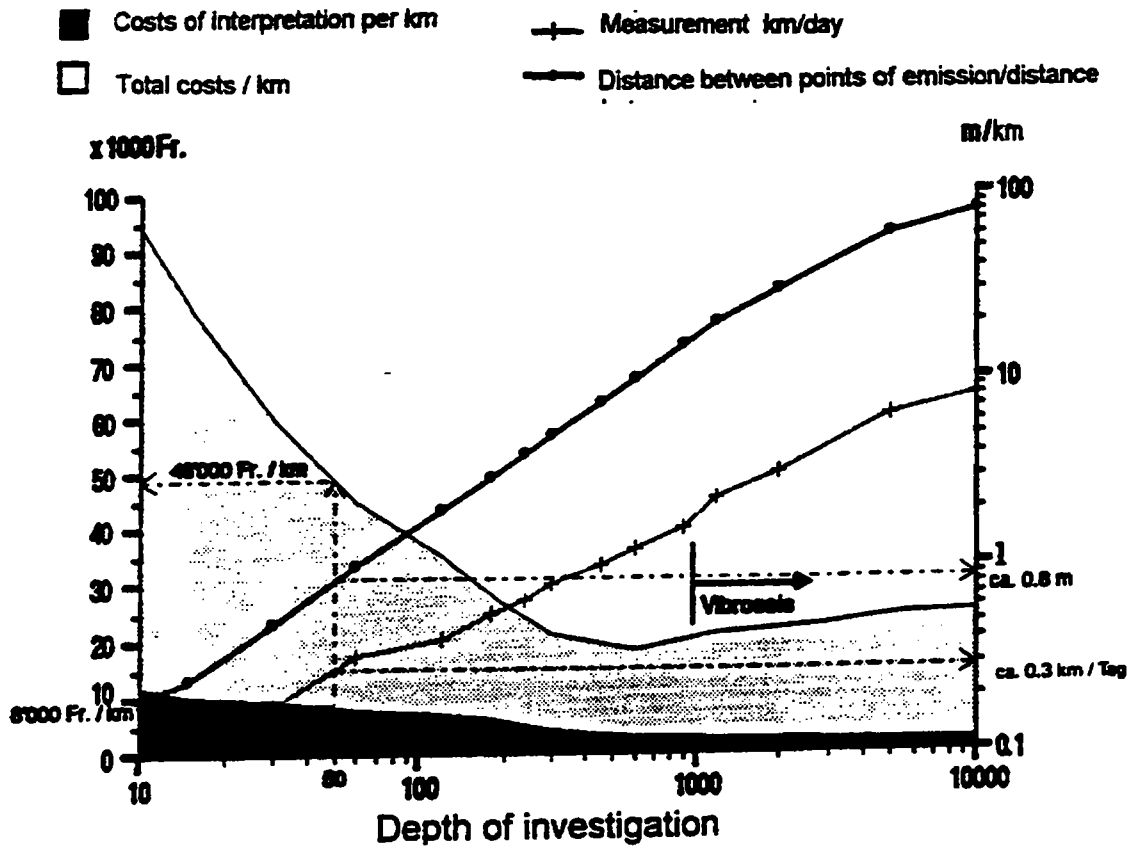
The table 2 provides a comparison of the two methods:

Table 2

	Refraction seismics	Reflection seismics
velocity determination	very good	good
thickness	very good	very good
geometry	weak	very good
complex geological situation	bad	very good
price	cheap	expensive

An estimate of the price of the shallow reflection seismic is given in Fig. 3 in relation to the depth of investigation.

Fig. 3: Estimate of the cost of the shallow reflection seismic.



3.3 Gravimetry

This method is based on the difference of density. After applying various corrections to the raw data, gravity anomalies can be mapped. The gravimetric maps show the distribution of heavy and light masses in the subsurface. It is also possible to discern a dense limestone from relatively lightweight clay in a karst system. This method is seldom applied in the investigations of raw materials for cement.

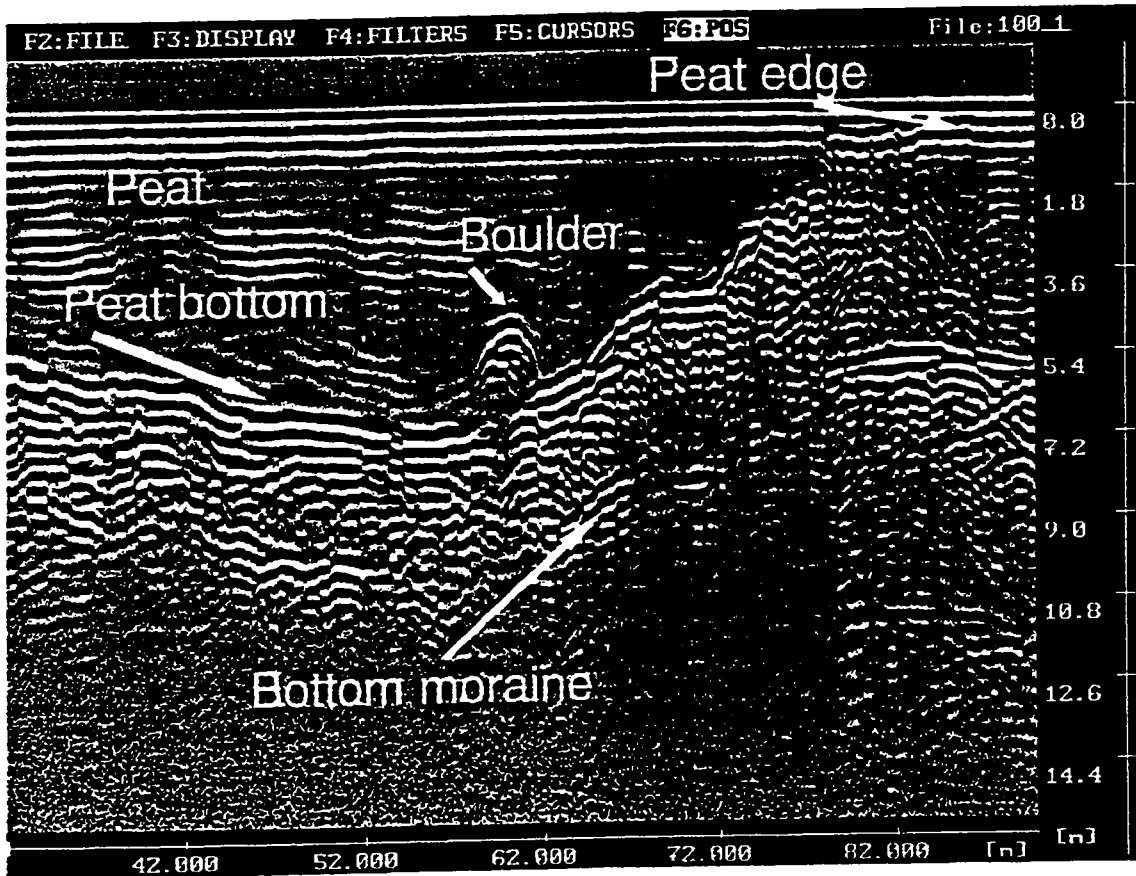
3.4 Geomagnetics

Geomagnetic method is the measure of the geomagnetic field on the surface. Iron-ore deposits are particularly suitable for investigation with this method, but it is less suitable for investigations of raw materials for cement.

3.5 Radar

Radar is a new method of prospecting, based on the electromagnetic waves. The tools consist of two antennae - transmitter and receiver. The transmitter generates electromagnetic impulses of 22 up to 100 MHz frequency. The depth of investigation depends on the frequency and of the mineral composition of the subsurface. An example of a radar is shown in Fig 4.

Fig. 4: Results of a radar investigation in a peat deposit



3.6 Bore hole logging

Nearly all geophysical parameters can be measured in drill holes in order to define the nature and the quality of the rocks. This is especially convenient when no core samples are available (reverse circulating drilling), or when core recovery is very poor. Nowadays slimhole logging offers extraordinary flexibility thanks to the fact that probe series containing up to 7 probes can be assembled as desired. Thereby, the number of runs needed is minimised and substantially reduces the field operation times.

A new logging tool is now available in the petroleum industry to determine the chemical composition of the rock in the drill hole. The geochemical logging tool measures concentrations of 12 elements (SiO₂, Al₂O₃, Fe₂O₃, CaO, SO₃, K₂O, TiO₂, Cl, Ga, H, Th, U) and provides data to calculate the MgO concentration of the formation. The accuracy of this tool must still be tested for use in the investigation of raw materials for cement.

3.7 Choice of method

The choice of method of application depends on the contrast of the physical parameters between the different rocks. The charts (Fig 5) show the expected physical value for different rocks and sediments.

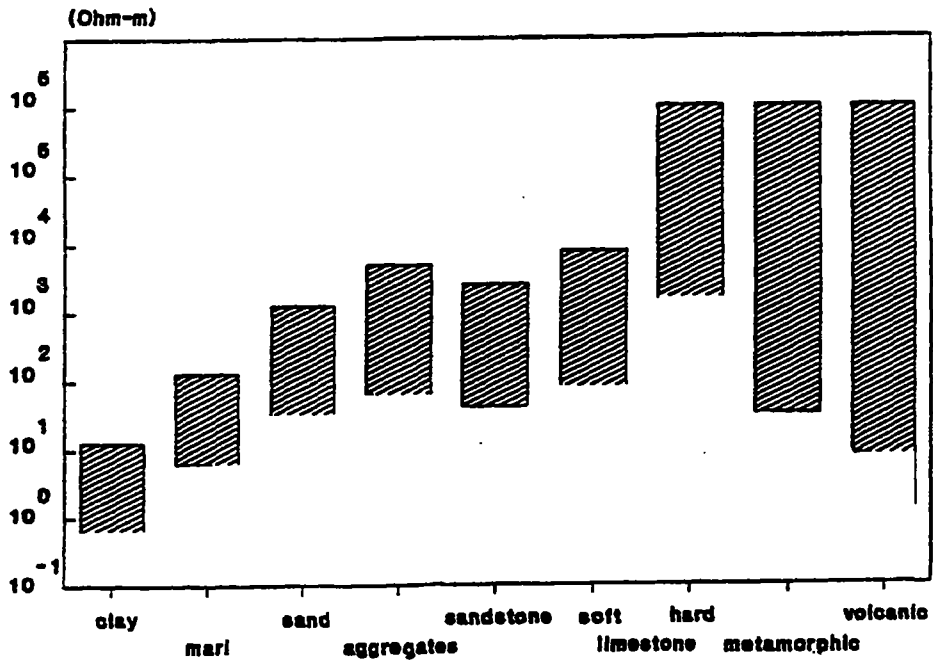
- ◆ geoelectrics: parameter is resistivity
- ◆ seismics: parameter is velocity

For instance, to determine the contact aggregates - sandstones, the best method would be seismics because of the better contrast of velocity between aggregates and sandstones.

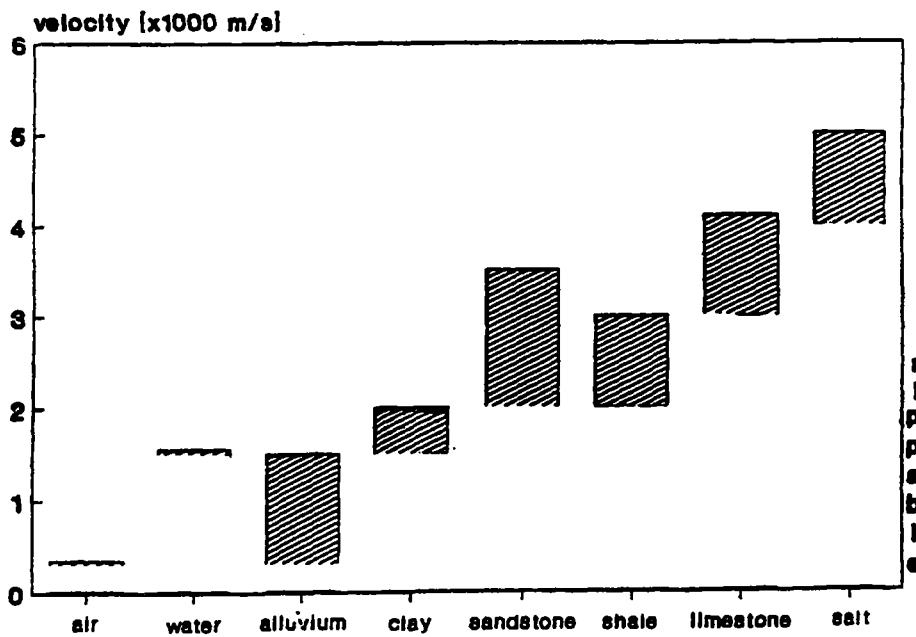
In conclusion, geophysics is an indirect method of investigation. The results must be interpreted in geological terms. The most important advantage of the geophysics is the quick execution at lower costs by keeping a low profile in the field. The choice of the method is dependent on the physical parameters between the layers under investigation.

Fig. 5 Physical parameters

Resistivity of different rocks



Velocity of different rocks



4. CASE STUDY

4.1 Determination of the contact basalt - granite

Geology

In a phase of extension of the aggregates quarry, the reserves of basalt must be accurately defined. The deposits consist of the following lithologies:

- ◆ overburden: fluvial sand and moraine
- ◆ basalt with some intercalation of tuff
- ◆ granite

The top of the granite is weathered and consists of argillaceous material.

Method

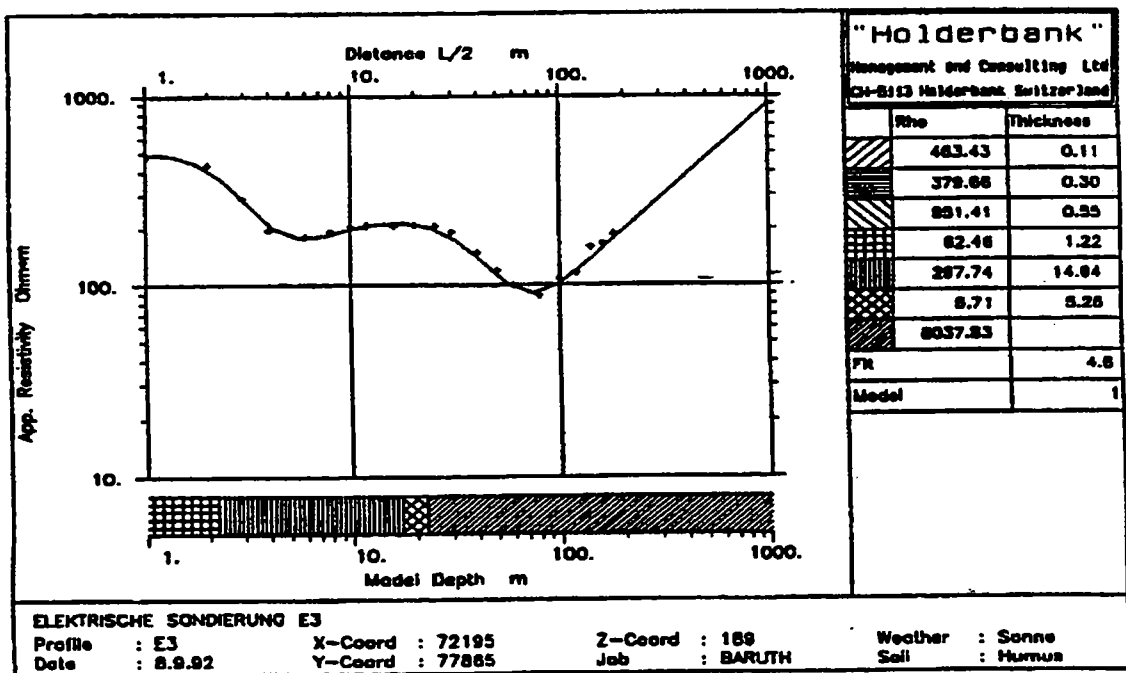
The weathered granite underneath the basalt shows a very good geoelectrical contrast. Indeed the argillaceous material has a very low resistivity, and can be easily detected by the geoelectrical methods.

Results of the geoelectrical prospecting

8 vertical electrical soundings and four poles profiling were carried out.

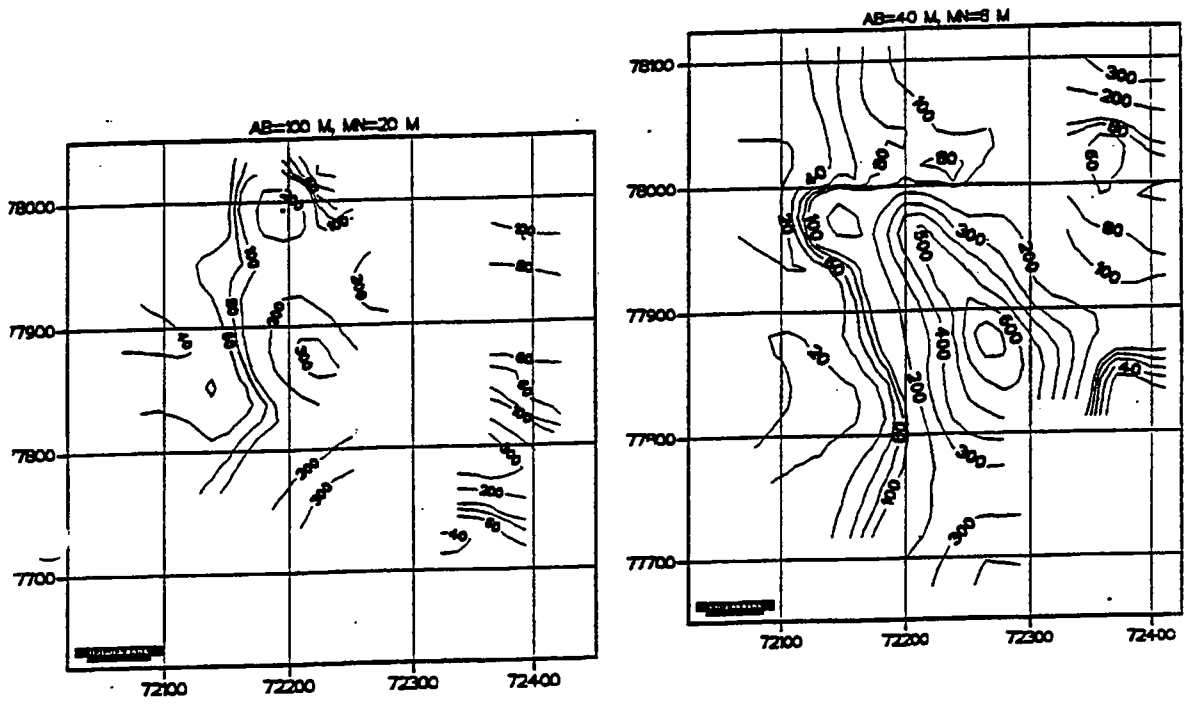
In the vertical soundings, the low resistivity layer under the basalt is clearly identified (Fig. 6).

Fig. 6: Interpretation of a vertical electrical sounding



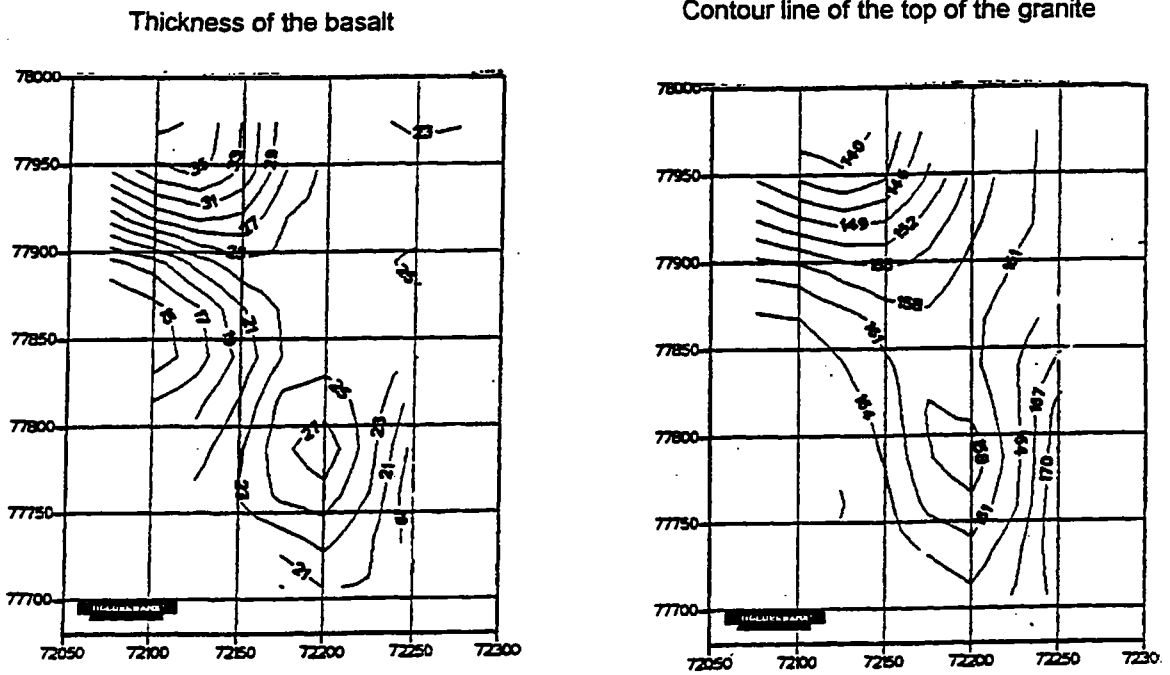
The apparent resistivity maps in Fig. 7 show the apparent resistivity for two different depths of investigation. The interpretation of these maps gives the geologist an indication of the structure of the subsurface for the investigated depth.

Fig. 7 Apparent resistivity maps



The result of this investigation is shown in the contour line map of the granite (Fig 8)

Fig. 8 Thickness of the basalt and contour line map of the top of the granite



4.2 Determination of the thickness of the lahar layers and their qualities

Geology

The field under consideration consists of several layers of lahar. A lahar consists of pyroclastic (volcanic) materials on the flank of a volcano. The deposit is produced by a landslide or mudflow. The quality of the lahar fluctuates due to the varying size of the matrix (coarse to fine grained). In this region, the lahar is overlaid by a volcanic tuff

Method

With vertical electrical soundings, the quality of the lahar can be appraised according to the fine materials in the matrix or the quantity of stone/gravel. Indeed, a fine matrix lahar or a sand have a true resistivity less than a sand matrix lahar containing many stones and gravel. The difficulty is to differentiate a fine matrix lahar from a sand layer, because it could have the same true resistivity.

The overburden (tuff) can be easily determined by geoelectrics due to the anticipated low resistivity.

Results

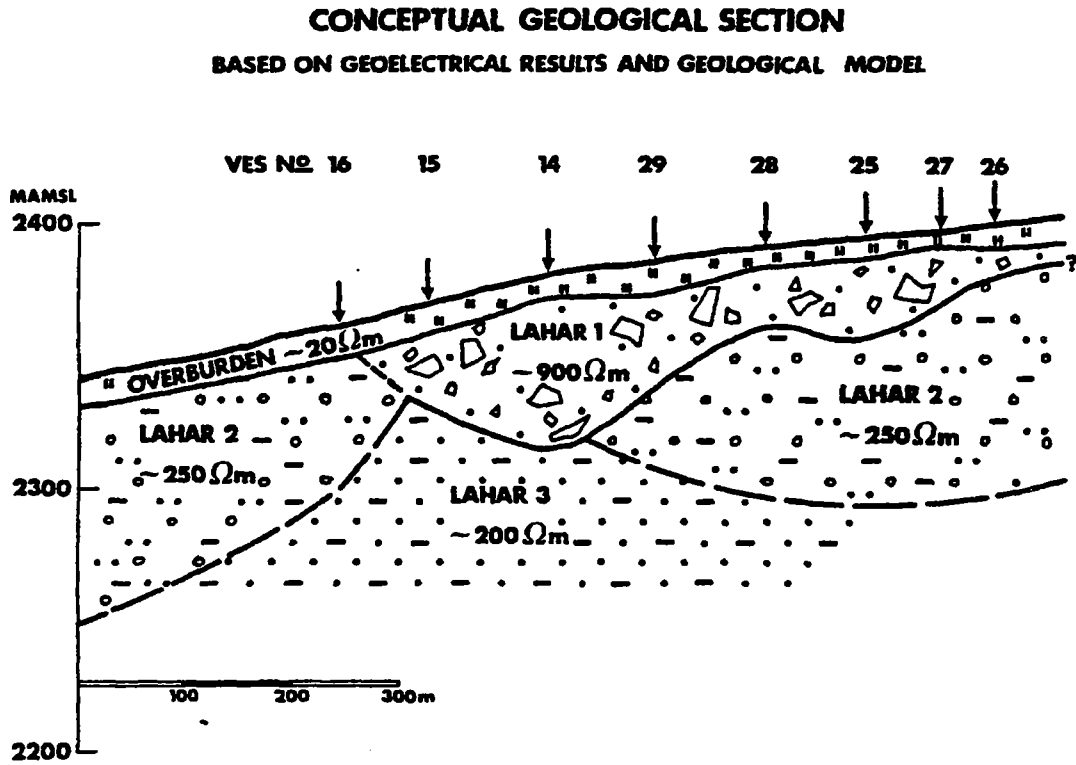
According to the results of the vertical soundings, three types of lahars have been determined. The true resistivity of the different lahars is as follows:

- ◆ Lahar 1: 600 to 1300 Ohm*m. Is considered to be of good quality. The highest resistivity indicates a consolidated lahar
- ◆ Lahar 2: 150 to 500 Ohm *m. Could correspond to a lahar with a fine matrix, or a sand with stones and gravel.
- ◆ Lahar 3: 90 to 150 Ohm*m, corresponding to a sandy - silty layer

The overburden (tuff) has a true resistivity in the range of 10 to 30 Ohm*m.

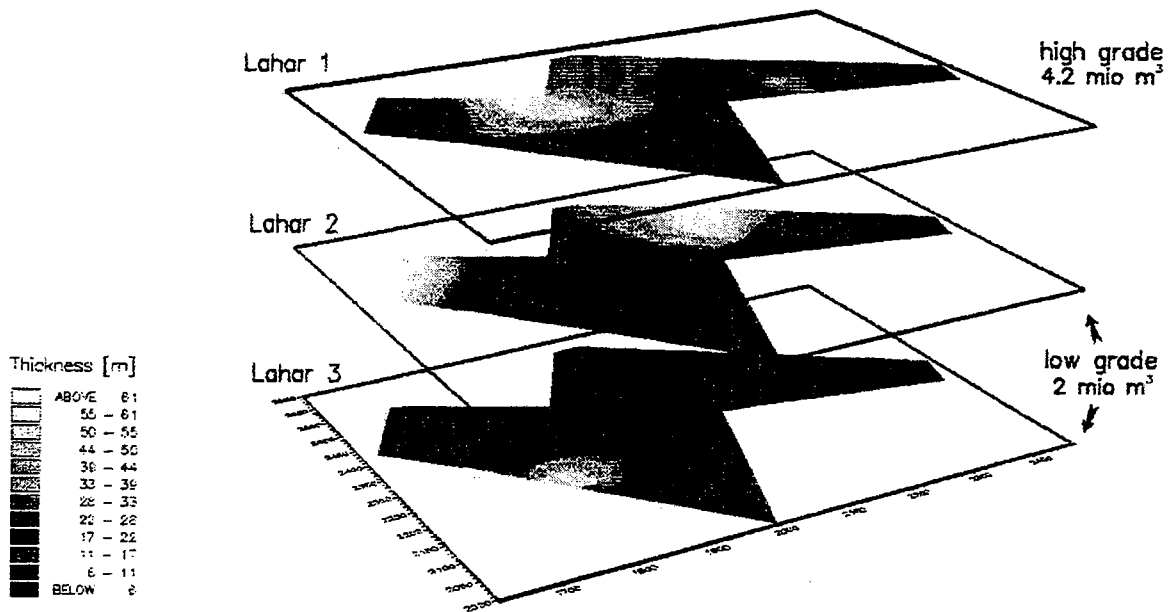
On the basis of the VES, a geological cross section is carried out (Fig 9).

Fig. 9: Conceptual geological section based on geoelectrical results.



The results are shown in isopach maps, maps representing the thickness (Fig 10).
It was recommended to put down a few drill holes of calibration.

Fig. 10: Thickness maps of the lahar layers



4.3 Determination of the overburden thickness

Geology

The region under consideration consists of marl. In a tropical climate, the upper part of the marl is completely weathered in kaolinite. The thickness of the weathering layer has to be determined.

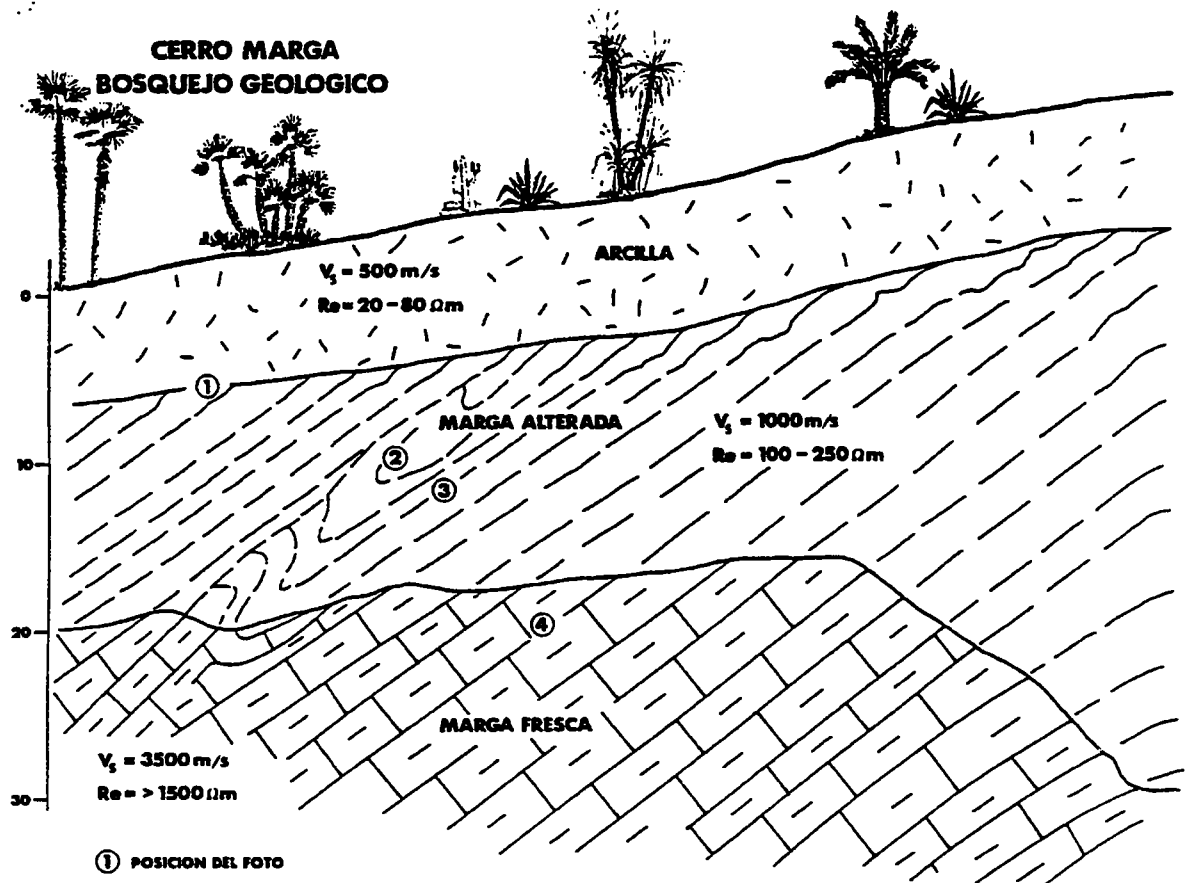
Method

The application of the refraction seismics in this situation has been considered because of the difference of velocity between the argillaceous weathered layer and the marl.

Results

With the refraction seismics, three layers have been determined. A profile is shown in Fig. 11. The considerable thickness of the weathered zone was prohibitive for exploitation.

Fig. 11: Geological cross-section based on the results of refraction seismic



4.4 Determination of the geological structure

The purpose of this investigation was to determine the structure of the bed rock under an overburden. The overburden consists of moraine and landslide materials.

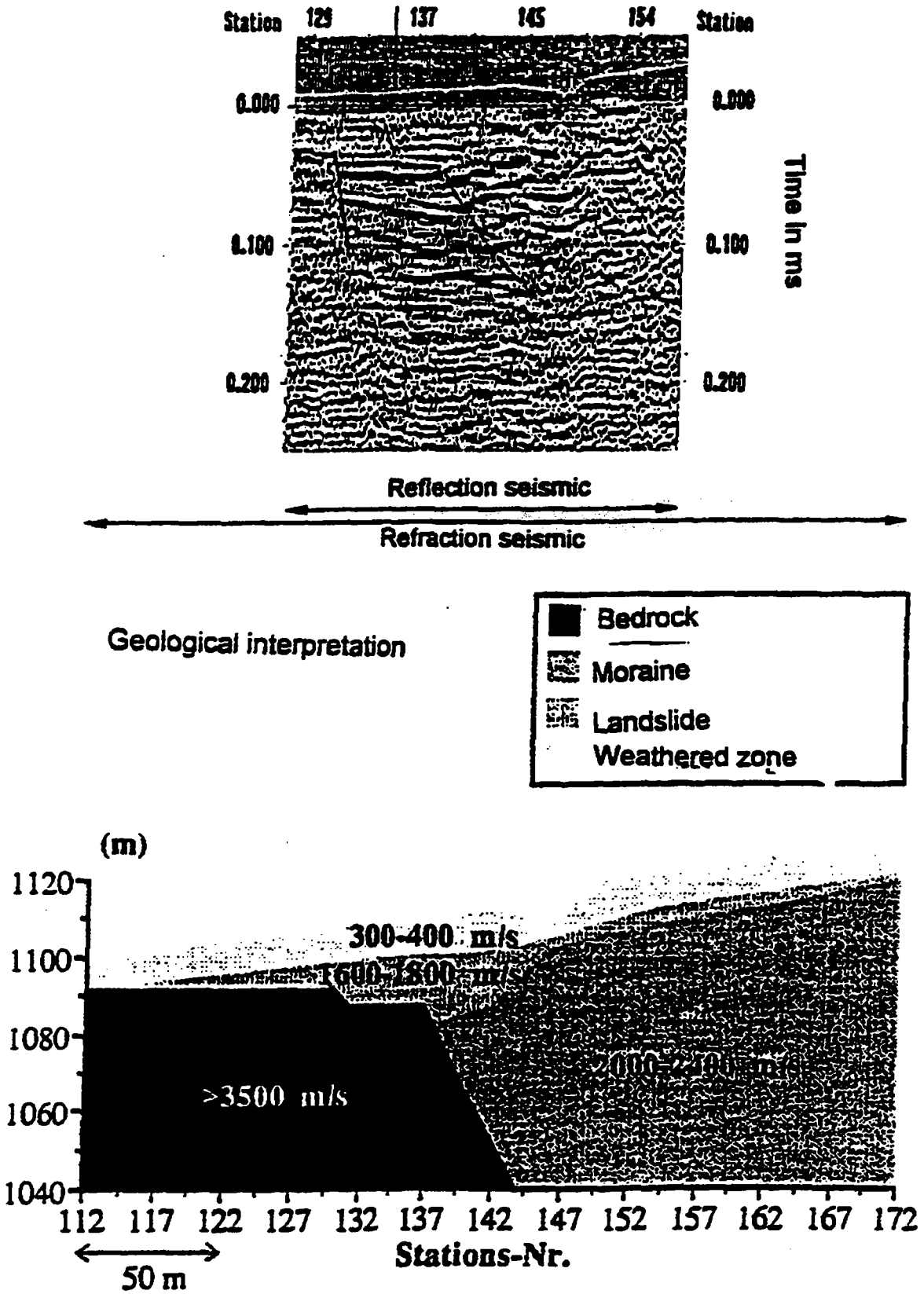
Method

Reflection seismics are applied accurately to determine the geometry of the bedrock

Results

The results of this investigation are shown in Fig 12.

Fig. 12: Profiles of reflection seismic and geological interpretation



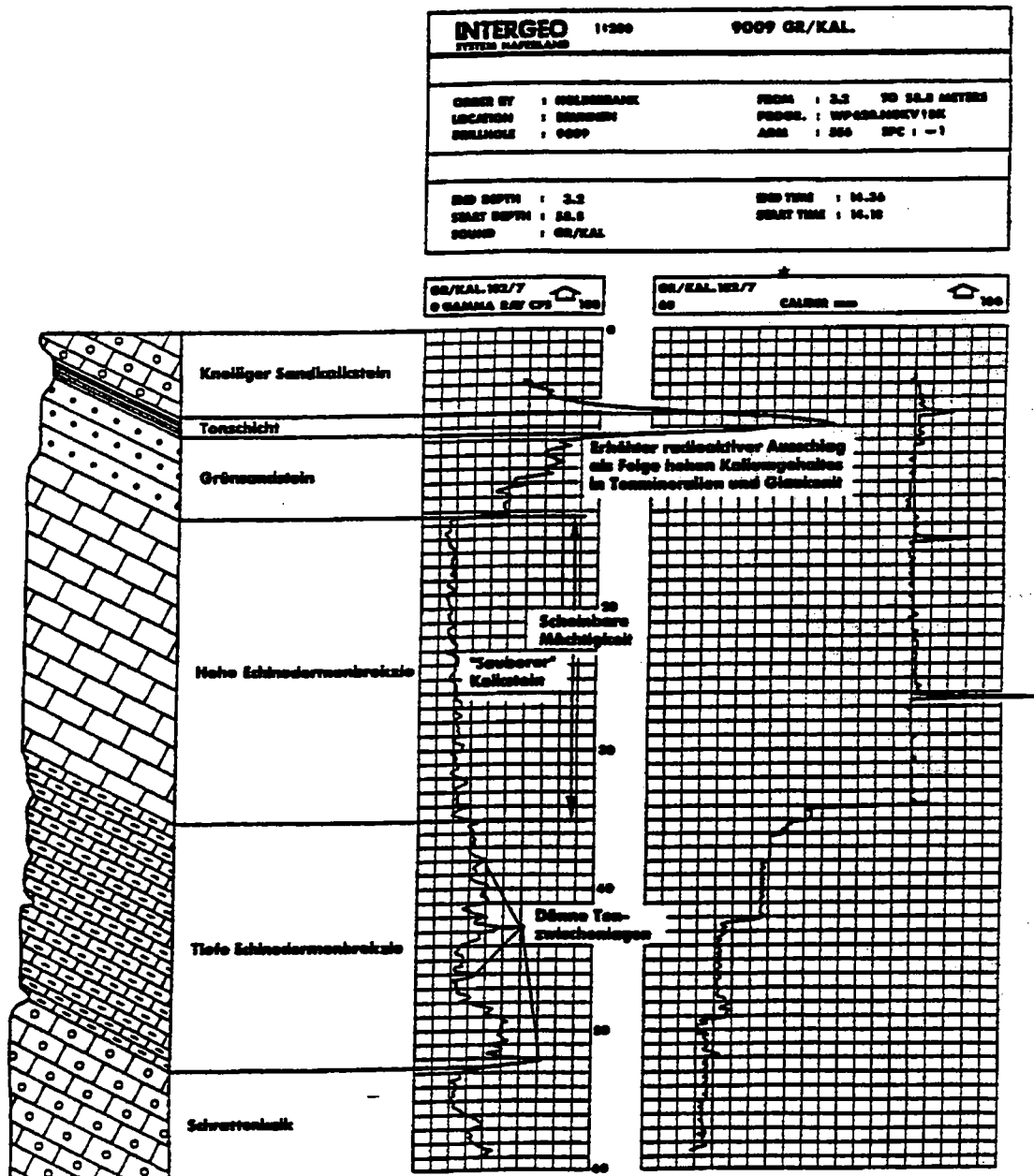
4.5 Evaluation of reverse drill hole

In the investigation of raw materials, the drilling campaign was carried out by reverse circulating drilling. No core was recovered. In order to determine the lithological contact and to localise thin interbeds of clay, a natural gamma ray logging was carried out.

With the present situation, the localisation of the thin interbeds of clay was indispensable for geotechnical purposes. The bench stability was precarious.

The results of the gamma ray logging is shown in Fig 13.

Fig. 13: Interpretation of gamma ray logging



The lithological contact as well as the thin interbeds of clay are clearly identified.

4.6 Karstified limestone

Recognition of cavities and determination of their size is always an important factor in geotechnics.

Preliminary drill holes had shown that the subsurface consists of strongly karstified limestone. Due to the lack of correlation between them, it was impossible to obtain a realistic image for the geotechnical calculation. A special logging tool was used by EBRA - Tee.

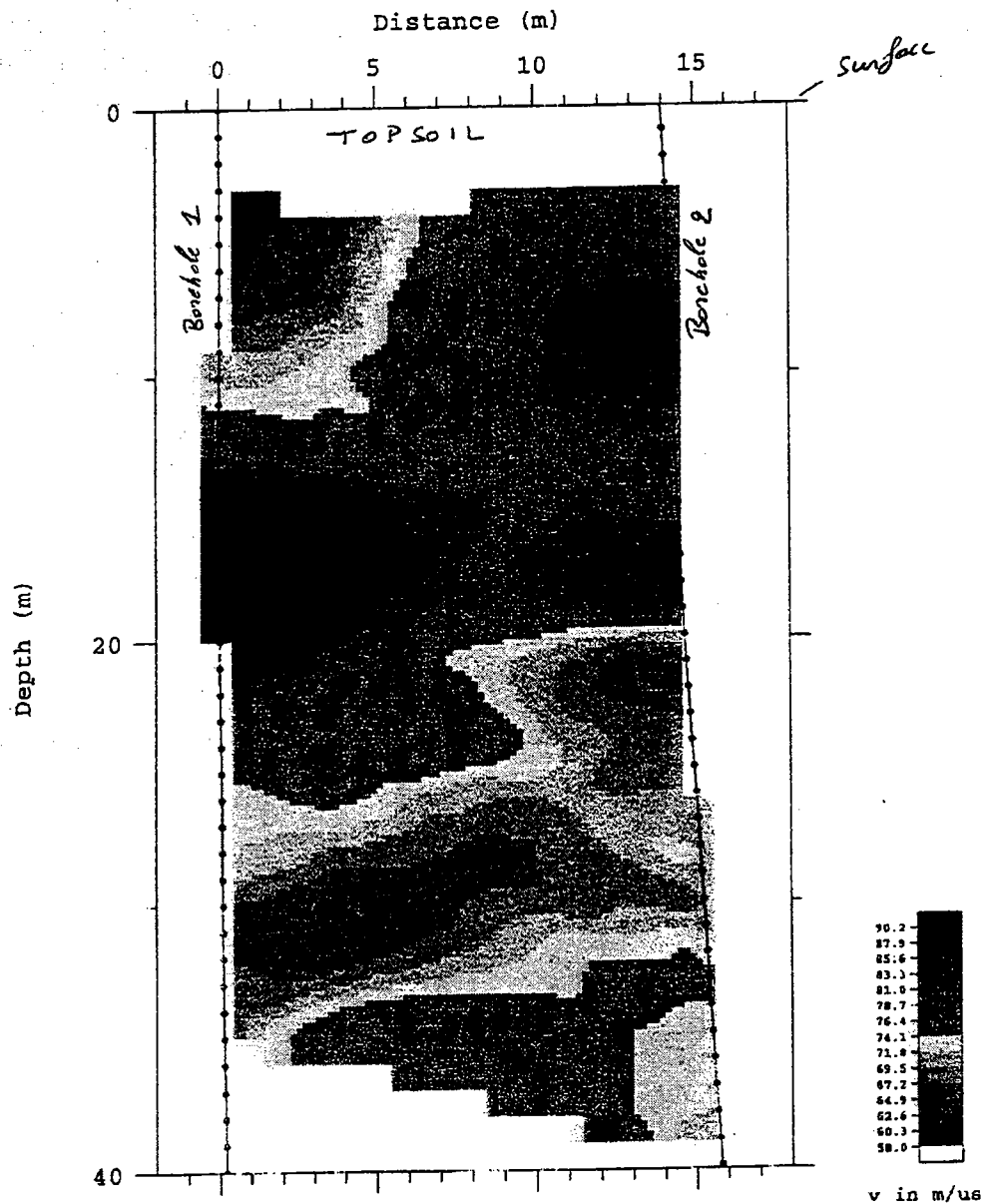
A radar tomography campaign has been carried out on each drill hole pair. Spacing between two drill holes ranges from 12 to 24 m.

Fig 14 shows the results of the tomography.

Fig. 14a: Radar tomographic measurements

EBRA - tec European borehole radar services

Electromagnetic tomographic measurements

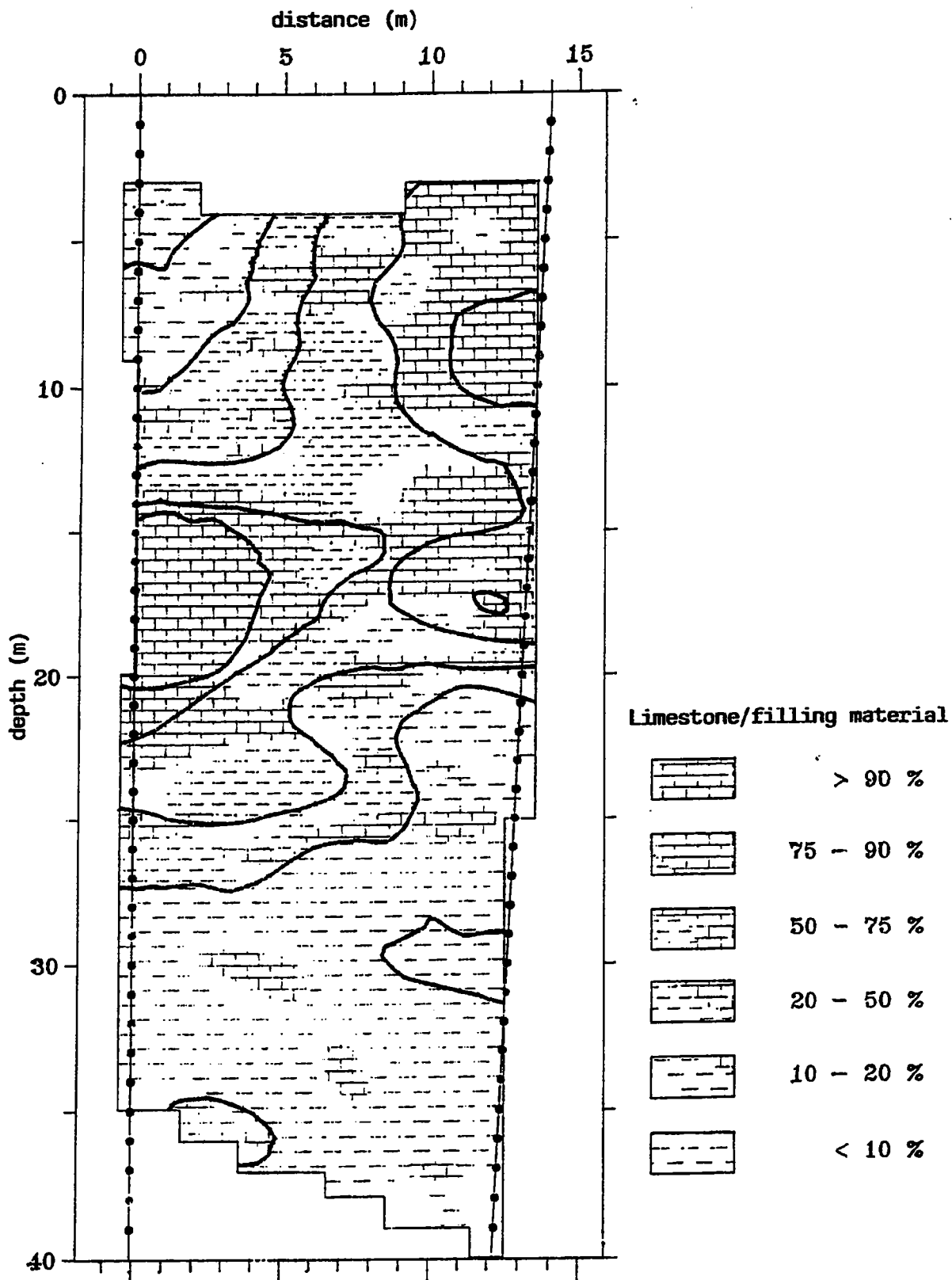


Electromagnetic tomographic measurements for the exploration
of the foundation soil of a HST - bridge in Belgium

Radar velocity tomogram

Center frequency: 22 MHz

Fig. 14b: Geological interpretation



Geological interpretation of radar velocity tomogram